Course Structure and Description

Machine Elements & Mechanisms I (ME&M-I)

PART I

- Introduction into the theory of Planar Mechanisms: Statics, Kinematics, Kinetostatics and Dynamics; Mechanisms with Bars, Screws, Gears and Cams;
- Introduction to Mechanical Engineering Design: Springs and Threaded Fasteners & Power Screws

PART II

MEM-II Subjects:

- Shafts
- Keys
- Bearings
- Friction assemblies

PART III

Mechanical transmissions:

- Gears
- V-belt Pulleys
- Couplings/clutches
- Friction drives

Chapter 2 (Machine elements) **Threaded Fasteners & Power Screws**

- Definitions, introduction, history
- Terminology, Screw thread types
- Thread uses: Threaded Fasteners, Locking Mechanisms and Power Screws
- Standardization – Types of screws, nuts, washers
- Metric screw – Main dimensions, Classification
- Forces and moments acting in a screw pair
- Efficiency of a threaded pair (solutions for increased efficiency)

Brief history

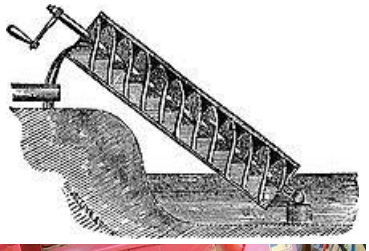
Ancient time:

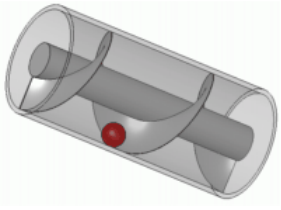
- Egyptians: lever, wedge (inclined plane), log roller – construction of pyramids;
- Mesopotamia: wheel and pulley (axle);
- Greeks: Arhimede from Siracusa (water screw), Archytas from Tarent (screw), Aristotel from Stagira (friction wheels and gears), Heron from Alexandria (syringe mechanism);
- Romans: military applications (catapults, wall scaling apparatus) and civil applications.

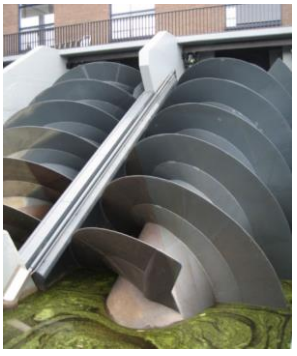
Modern time:

- Leonardo da Vinci, Galileo Galilei,
- Isaac Newton, James Watt,
- Leonhard Euler, Joseph-Louis Lagrange,
- Franz Reuleux, Robert Willis,
- Gaspard Monge, Jean Nicolas Pierre Hachette,
- Pafnuty Chebyshev, Ivan Ivanovichi Artobolevsky
- Henry Brown
- Kurt Hain, Richard Hartenberg and Jacques Denavit

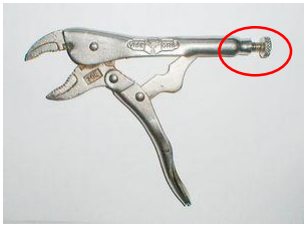
Archimedes water screw



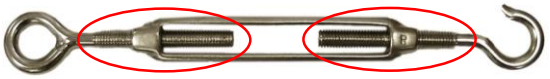




Thread parts used in tools and devices



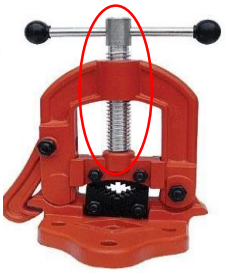
Adjustable locking plier
(four-bars mechanism)



Turnbuckle

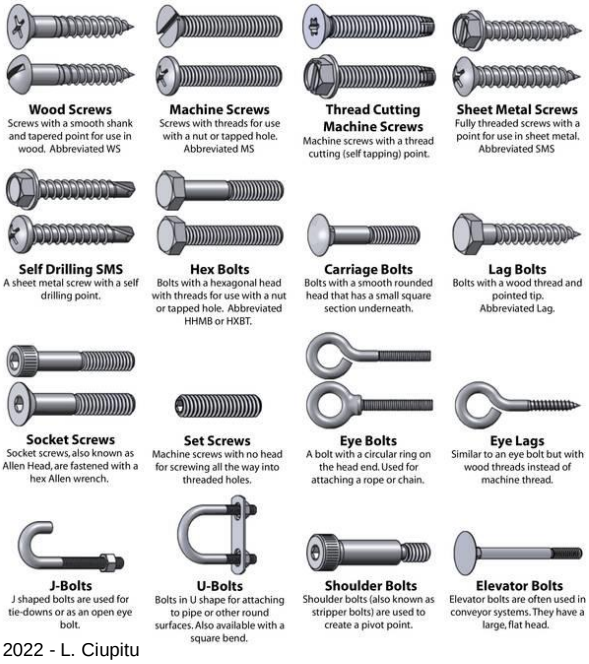
Scissor screwjack

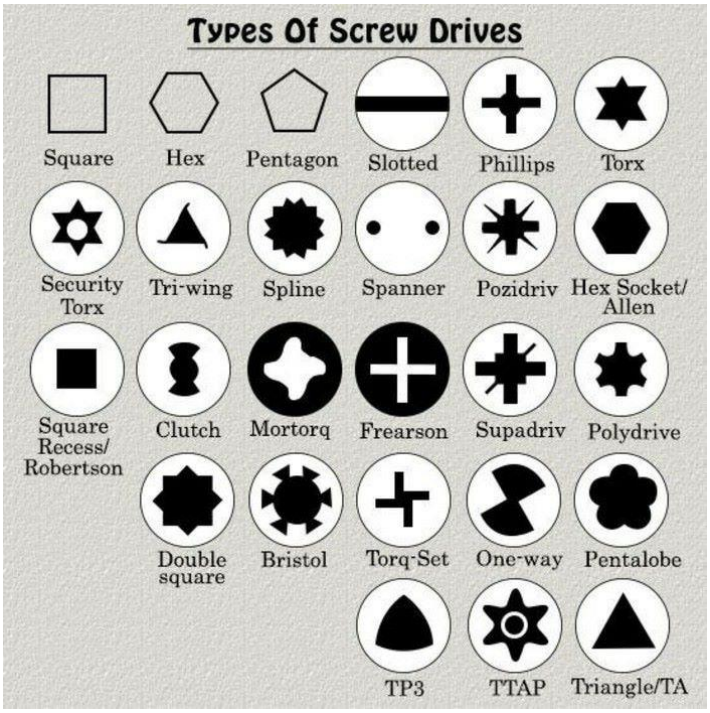
Screwjack with
rotating nut



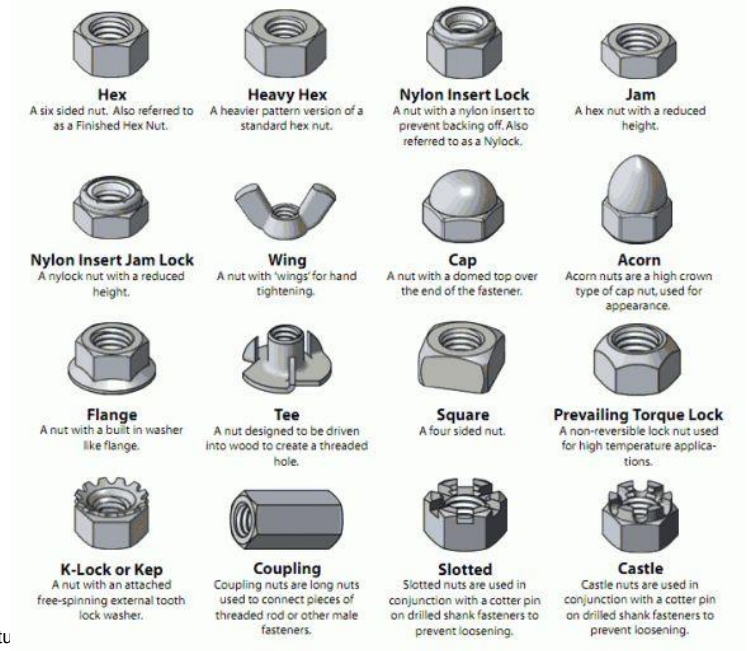
Pipe-vice

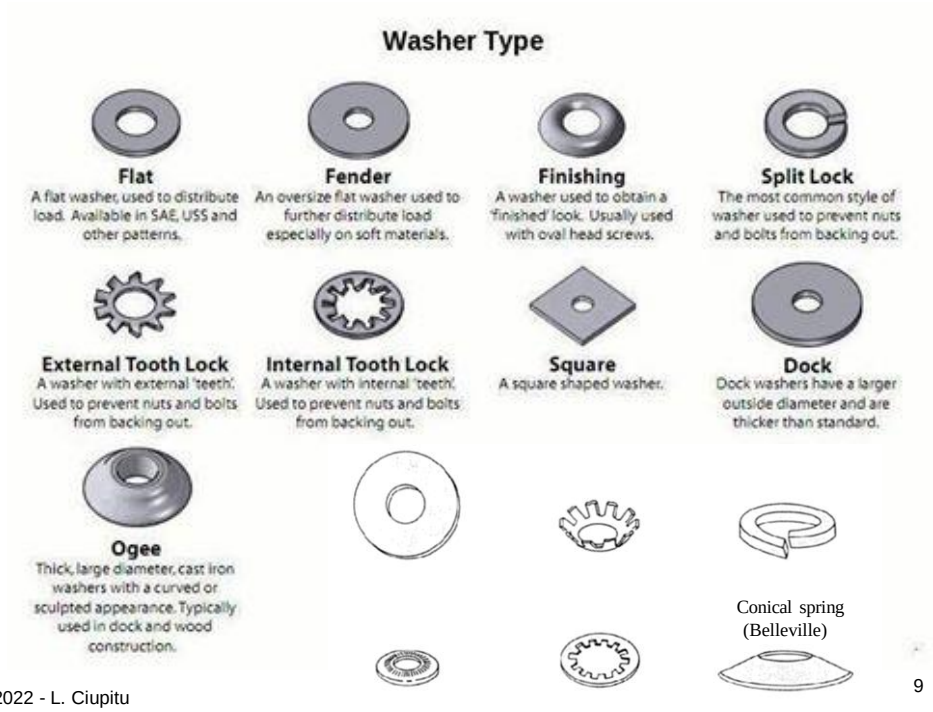
Screws and Bolts




Types Of Screw Drives
Square
Hex
Pentagon
Slotted
Phillips
Torx
Security Torx
Tri-wing
Spline
Spanner
Pozidriv
Hex Socket/ Allen
Square Recess/ Robertson
Clutch
Mortorq
Frearson
Supadriv
Polydrive
Double square
Bristol
Torq-Set
One-way
Pentalobe
TP3
TTAP
Triangle/TA

Nuts


Hex
A six sided nut. Also referred to as a Finished Hex Nut.
Heavy Hex
A heavier pattern version of a standard hex nut.
Nylon Insert Lock
A nut with a nylon insert to prevent backing off. Also referred to as a Nylock.
Jam
A hex nut with a reduced height.
Nylon Insert Jam Lock
A nylock nut with a reduced height.
Wing
A nut with 'wings' for hand tightening.
Cap
A nut with a domed top over the end of the fastener.
Acorn
Acorn nuts are a high crown type of cap nut, used for appearance.
Flange
A nut with a built in washer like flange.
Tee
A nut designed to be driven into wood to create a threaded hole.
Square
A four sided nut.
Prevailing Torque Lock
A non-reversible lock nut used for high temperature applications.
K-Lock or Kep
A nut with an attached free-spinning external tooth lock washer.
Coupling
Coupling nuts are long nuts used to connect pieces of threaded rod or other male fasteners.
Slotted
Slotted nuts are used in conjunction with a cotter pin on drilled shank fasteners to prevent loosening.
Castle
Castle nuts are used in conjunction with a cotter pin on drilled shank fasteners to prevent loosening.



Washers

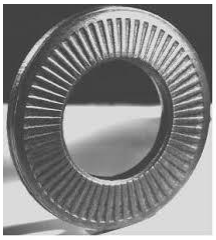
Flat washer

External tooth countersunk lockwasher

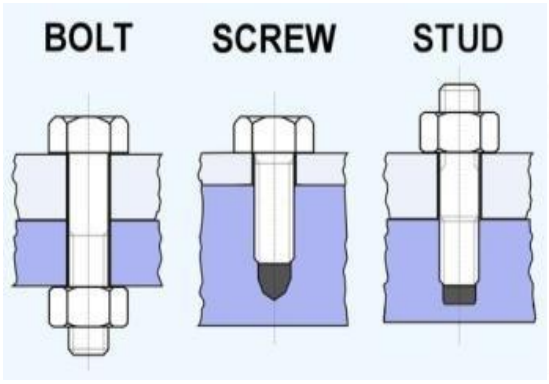
Internal tooth lockwasher

Coil spring washer
Helical spring/Split spring/ Lockwasher

Conical washer with hardened teeth. (Serrated washer)



Dedicated threaded components (fasteners)

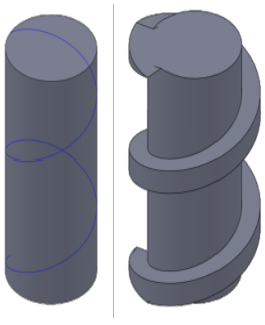


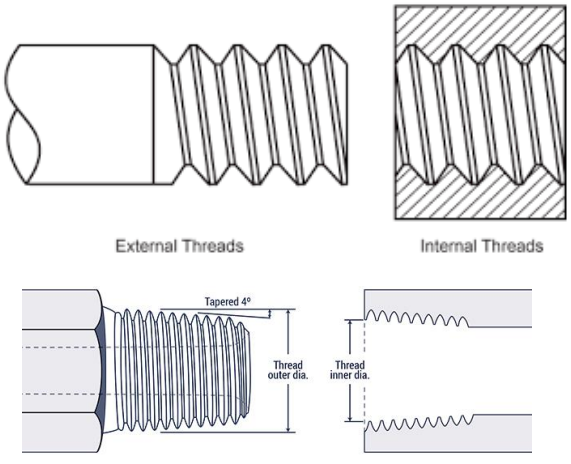
(1) Dedicated components - screws, bolts , nuts, studs, pins

(2) Various parts, threaded - caps, housings, wheels, etc

Thread

Thread is the ridge (channel) usually of uniform section, in the form of a helix with constant pitch, materialized on the external or internal surface of a cylinder or in the form of a conical spiral on the external or internal surface of a cone or frustum of cone.

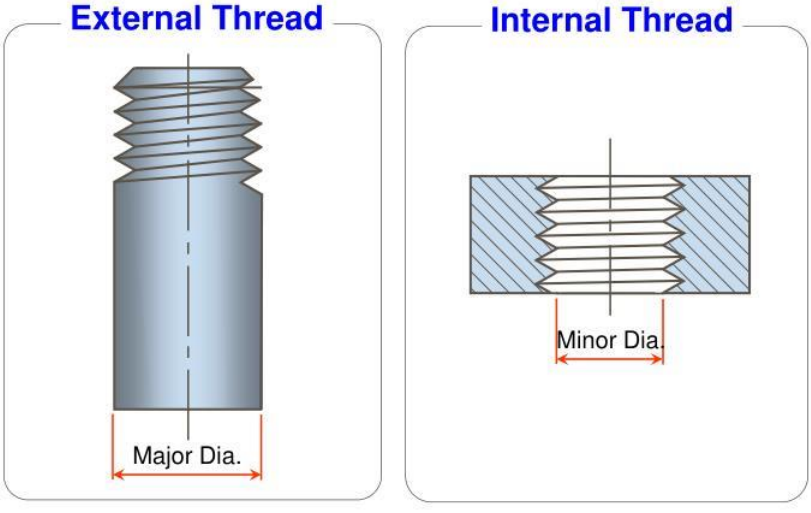




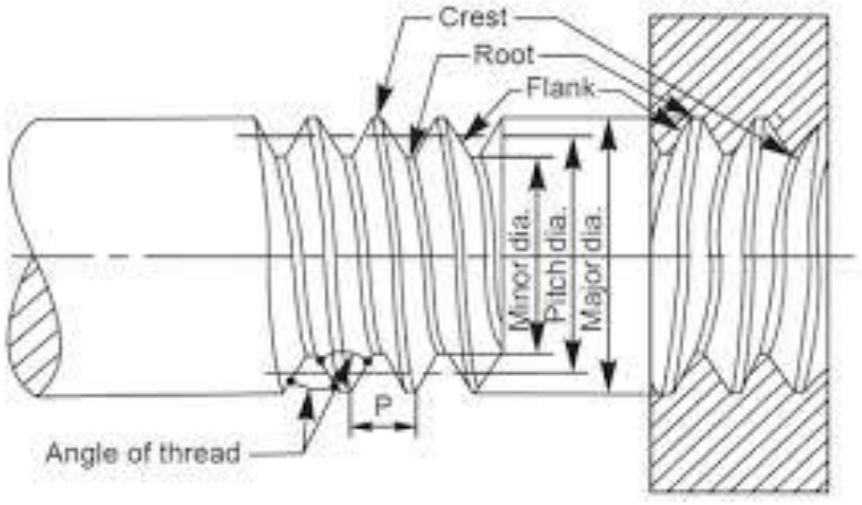
THREAD TERMINOLOGY

External (male) thread	A thread cut on the ***outside*** of a cylindrical body.
Internal (female) thread	A thread cut on the ***inside*** of a cylindrical body.

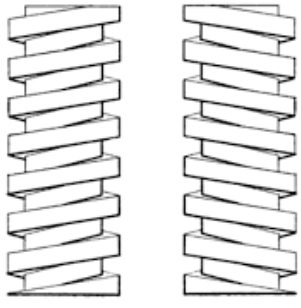
COMPARISON OF THREAD CUTTING



External and Internal Threads

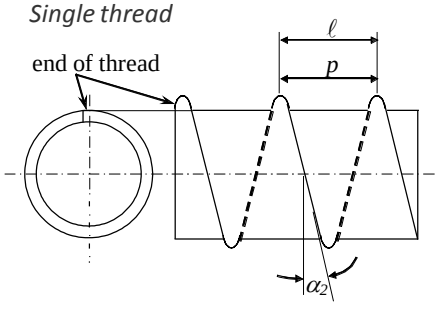


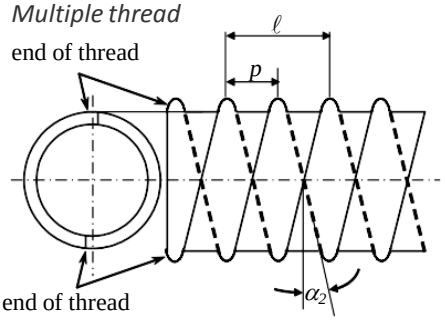
Thread - Classification



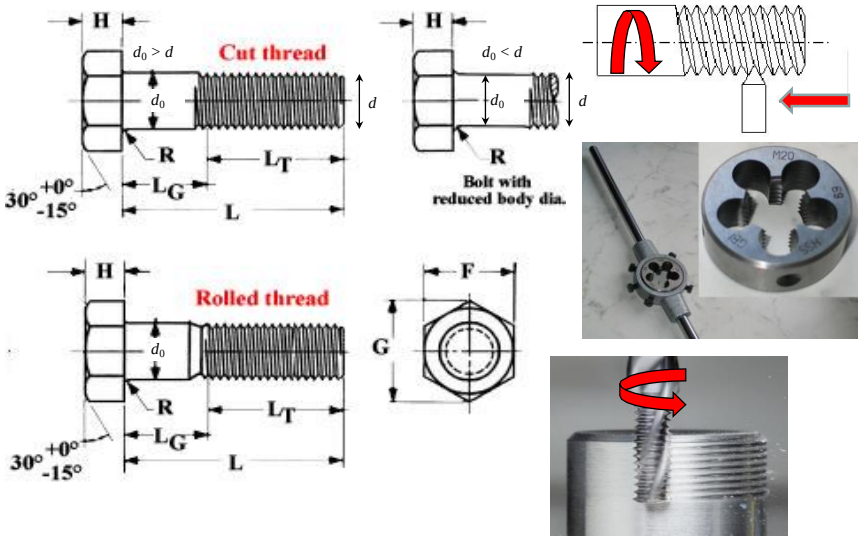
Lead, ℓ

Pitch, p

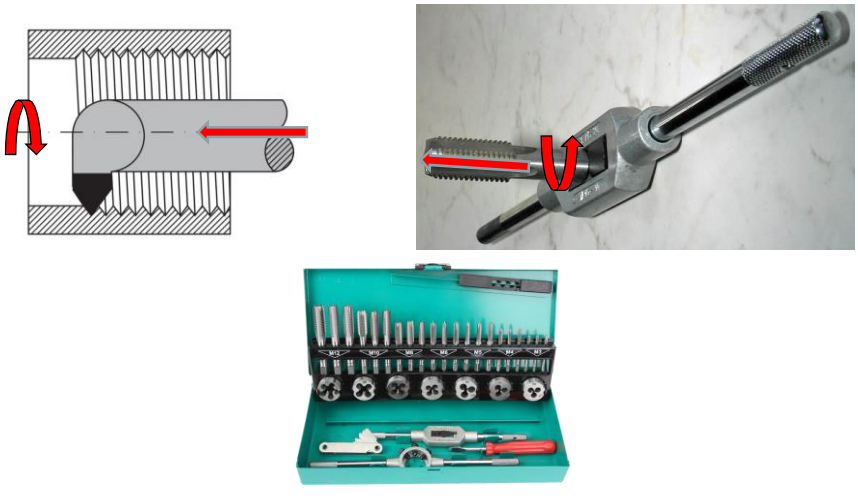




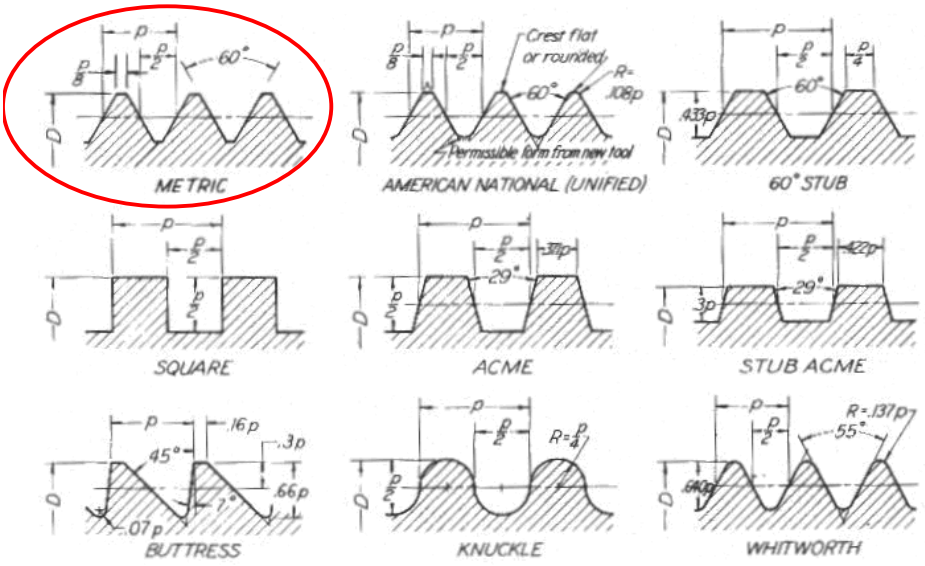
External Thread – manufacturing



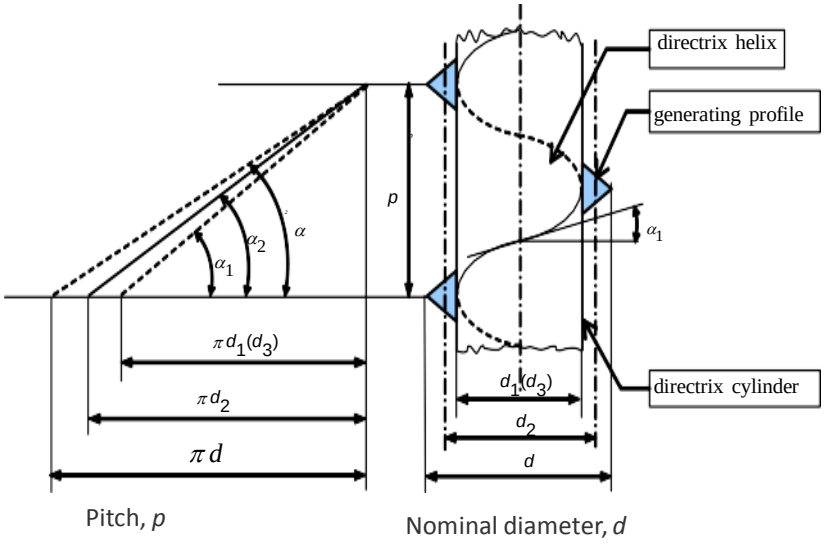
Internal Thread – manufacturing



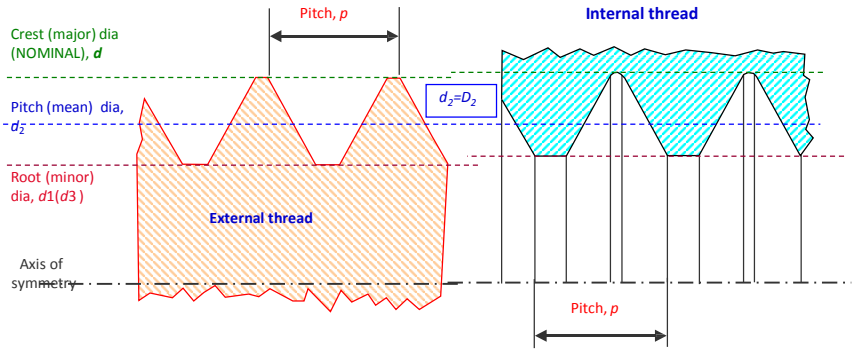
Thread cross section forms



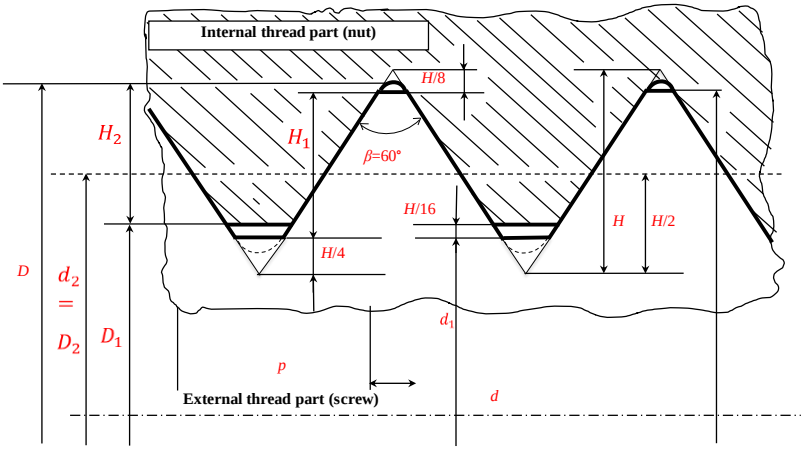
Thread – geometric elements



Metric Thread − Dimensions

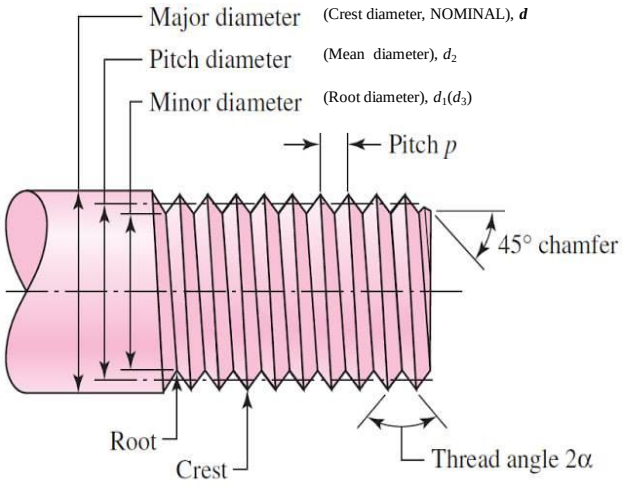


Assembly Threads − Dimensions



$H = 0.866\ p$ $H_1 = 5H/8 = 0.541\ p$ $H_2 = H_1 - H/16 = 0.487\ p$

Metric Thread − Dimensions



Terminology of Screw Threads

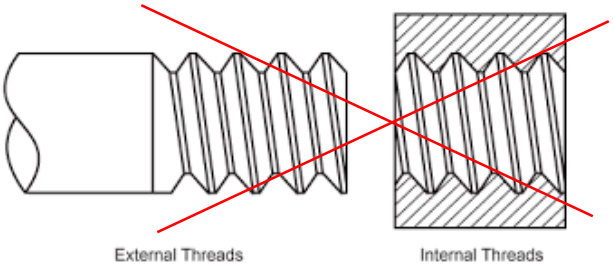
Example: M 40 x 1.5 LH

Metric type
d = 40 mm
p = 1.5 mm
Left-hand

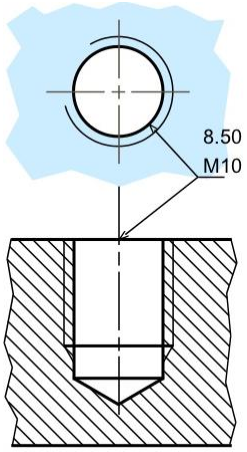
Other possible details
- Helix direction
- Class of tolerances
- Number of starts

Thread simplified representation

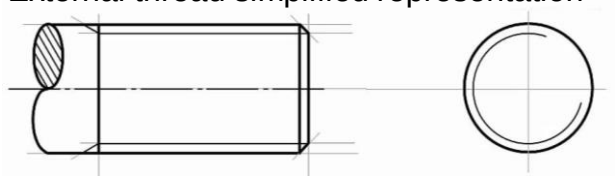
Never draw the thread as it is in reality !



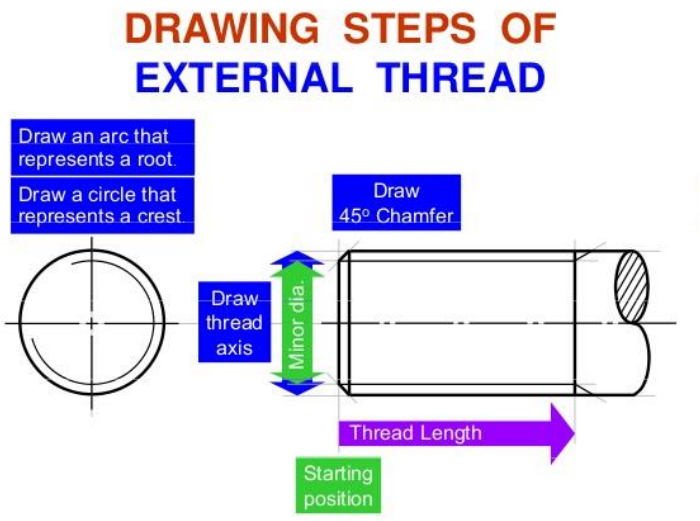
Internal thread simplified representation



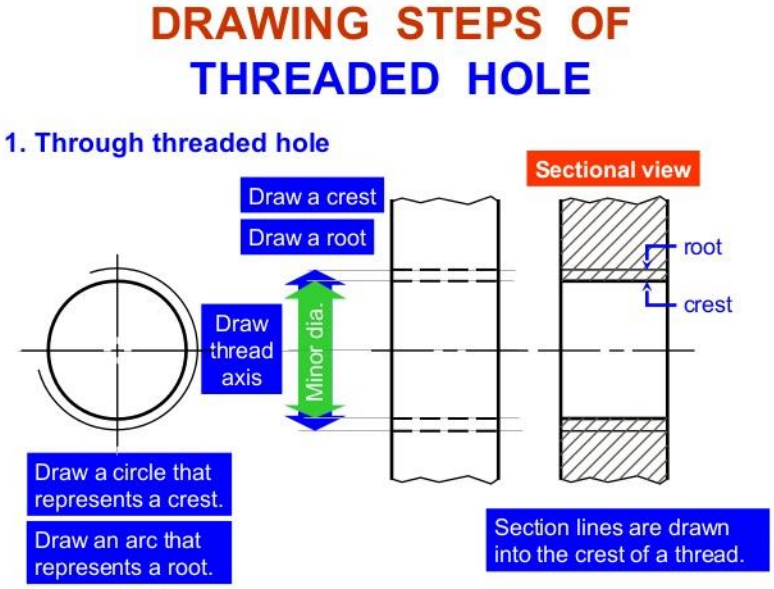
External thread simplified representation



Thread simplified representation



Thread simplified representation



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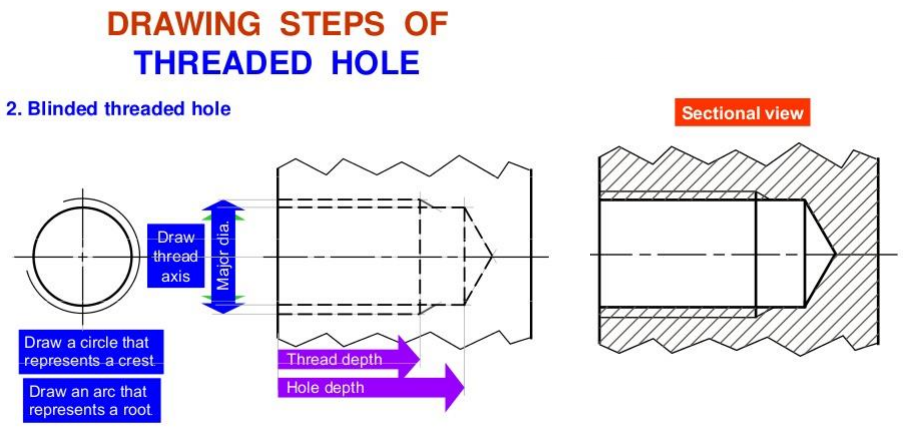
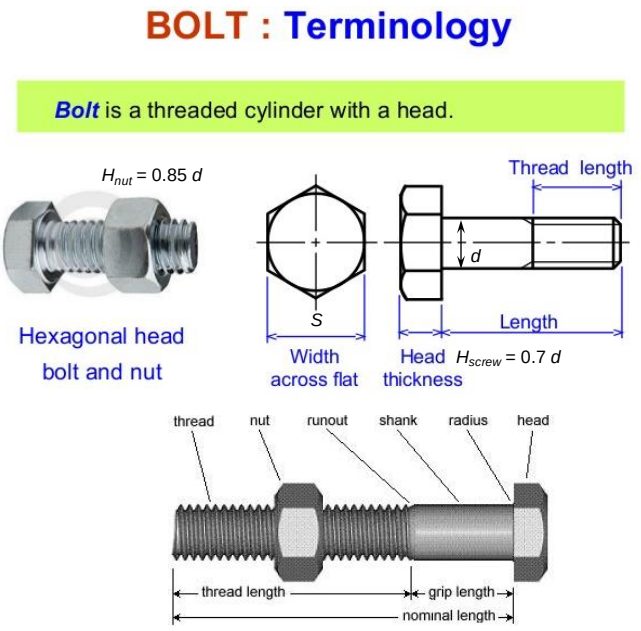
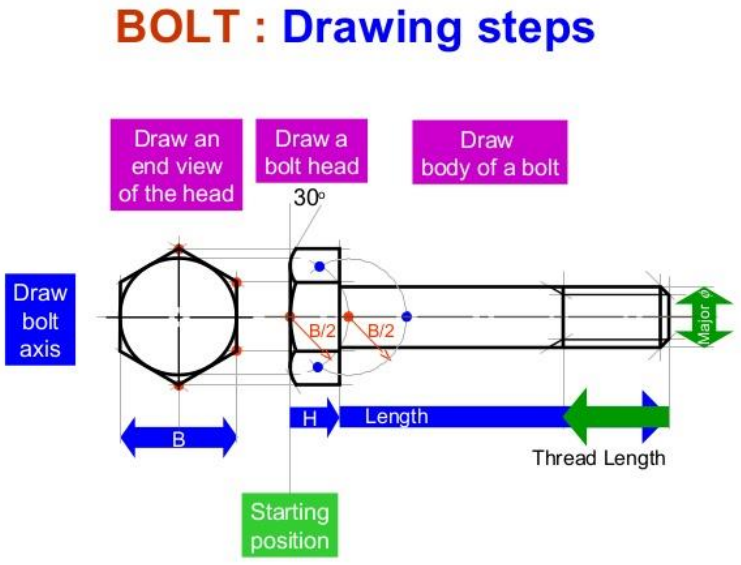


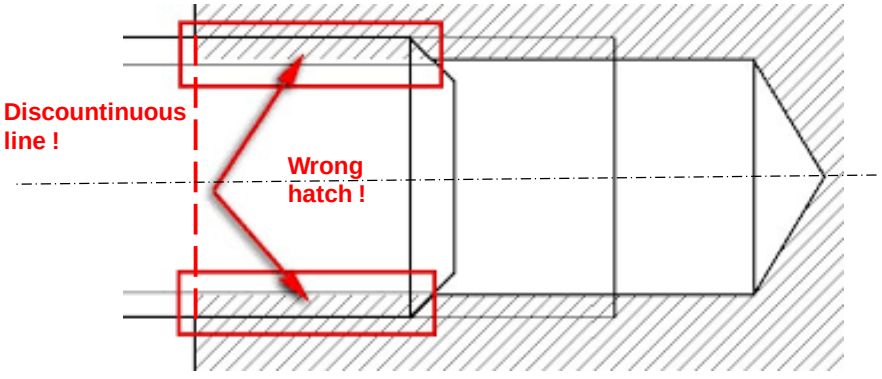
Thread simplified representation



Thread simplified representation

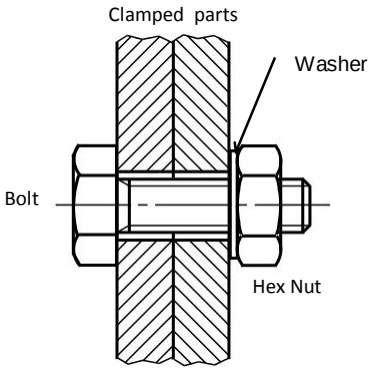


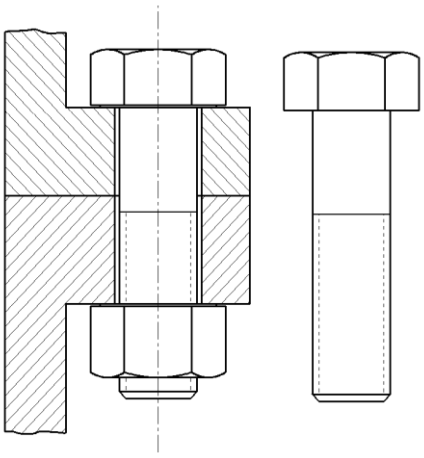
Thread simplified representation



Thread functions (1)

Fastening/Assemblying/Joining/Fixing/Clamping





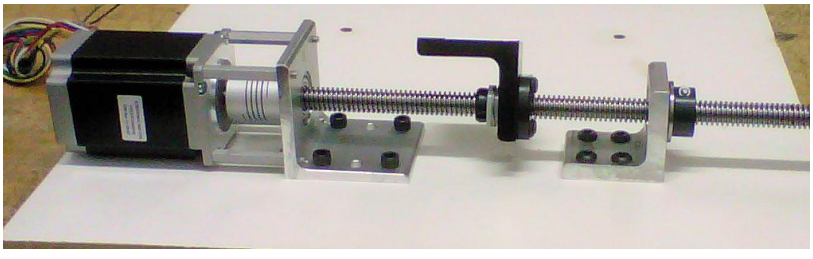
Also called: Clamping screw

Threaded fastener

Bolt-and-nut assembly / joint

Thread functions (2)

Convertion of the rotary motion into linear motion of either the screw or the nut, of itself or of the mating member along the screw axis



- Rotating screw – Translating nut
- Rotating screw – Translating screw
- Rotating nut – Translating screw
- Rotating nut – Translating nut

Also called

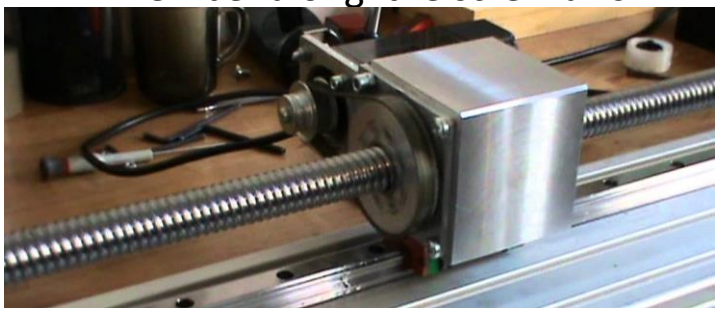
Lead screws

Translation screws

Linear actuators

Thread functions (3)

Convertion of the rotary motion into linear motion of either the screw or the nut, of itself or of the mating member along the screw axis



- Rotating screw – Translating nut
- Rotating screw – Translating screw
- Rotating nut – Translating screw
- Rotating nut – Translating nut

Also called
Lead screws
Translation screws
Linear actuators

Thread functions (4)

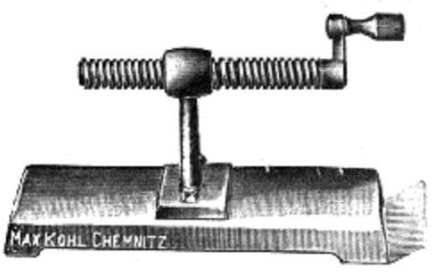
Convertion of the rotary motion into linear motion of either the screw or the nut, of itself or of the mating member along the screw axis

- Rotating screw – Translating nut
- Rotating screw – Translating screw
- Rotating nut – Translating screw
- Rotating nut – Translating nut

Also called
Lead screw
Translation screw
Linear actuator

Thread functions (5)

Convertion of the rotary motion into linear motion of either the screw or the nut, of itself or of the mating member along the screw axis



- Rotating screw – Translating nut
- Rotating screw – Translating screw
- Rotating nut – Translating screw
- Rotating nut – Translating nut

Also called
Lead screw
Translation screw
Linear actuator

Materials

1. **Power screw** - *power & motion transmission*

   HARD (STEEL) / SOFT (Cast iron, bronze) - to prevent excessive wear and seizure at high speed

2. **Fasteners** - *assembly*

Screw —
- Normal application - *low or medium carbon steel*
- Important application - *alloy steel (Mo, Ti, Ni-Cr)*
- Special application - *brass, high-resistance plastics*

Nut → *Phosphorous wrought steel, alloy steel, plastics*

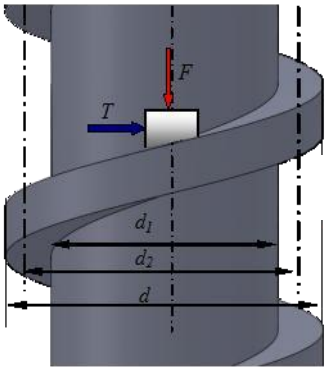
M40 x 1.5 - **6.8** **SCREW**

σ_u = min 6x100 = 600 MPa — σ_y = min 6x8x10 = 480 MPa

M40 - **6** **NUT**

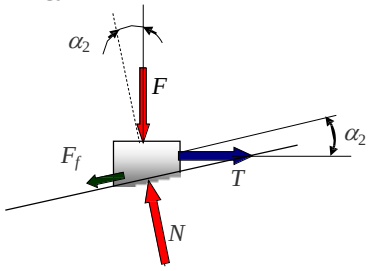
Forces and moments acting in a screw pair

a) detail of a square thread with a part of a nut



F – axial force T – tangential force

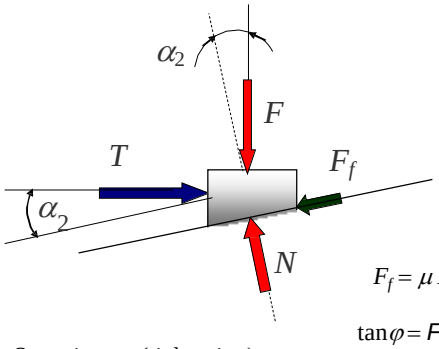
Analogy with WEDGE EFFECT

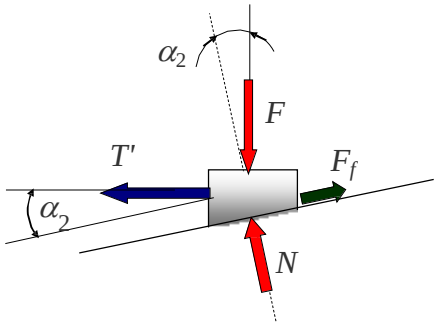


$$\vec{T} + \vec{F} + \vec{N} + \vec{F_f} = 0$$

$$\begin{cases} T\cos\alpha_2 - \mu N - F\sin\alpha_2 = 0 \\ -T\sin\alpha_2 + N - F\cos\alpha_2 = 0 \end{cases}$$

Forces and moments acting in a screw pair





Screwing up (tightening):

$T = F\tan(\alpha_2 + \varphi)$

$F_f = \mu N$

$\tan\varphi = F_f / N$

$\tan\varphi = \mu$

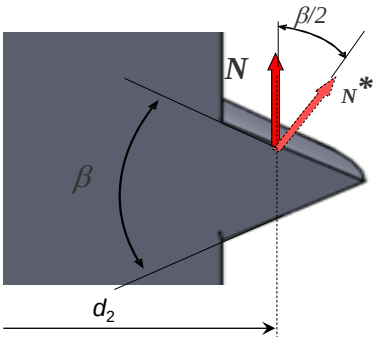
Self-locking condition

$\alpha_2 < \varphi$

Screwing down (loosening):

$T' = F\tan(\alpha_2 - \varphi)$

Correction for ISO Metric Thread (Inclined flank of the thread)



$$F_f = \mu N^* = \mu \frac{N}{\cos(\beta/2)}$$

$$\tan\varphi^* = \mu^*$$

$$\varphi^* = \operatorname{atan}\frac{\mu}{\cos(\beta/2)}$$

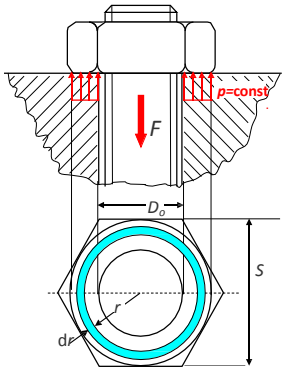
Screwing up (tightening):

$$M_{t1} = T\frac{d_2}{2} = F\frac{d_2}{2}\tan\left(\alpha_2 + \varphi^*\right)$$

Screwing down (loosening):

$$M_{t1} = T\frac{d_2}{2} = F\frac{d_2}{2}\tan\left(\alpha_2 - \varphi^*\right)$$

Collar (Underhead) friction torque



$$M_{t2} = \int_{D_0/2}^{S/2} \mu_c\, p\,(2\pi\, r\, \mathrm{d}r)\, r$$

$$M_{t2} = \mu_c \frac{F}{3}\frac{S^3 - D_0^3}{S^2 - D_0^2}$$

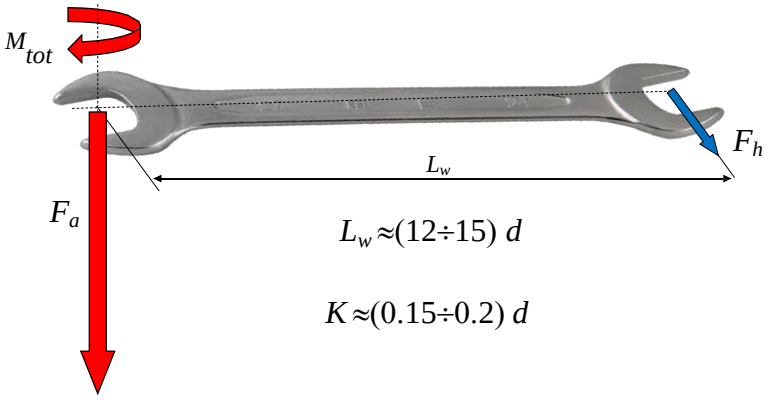
Aproximate formula:

$$M_{t2} = \mu_c F R_m \quad \text{where} \quad R_m = \frac{D_0 + S}{4}$$

Observation: Distance *S* should be replaced by washer external diameter if any

Total torque

Total torque (at wrench): $M_{tot} = M_{t1} + M_{t2} = K F_a = L_w F_h$



$L_w \approx (12 \div 15)\, d$

$K \approx (0.15 \div 0.2)\, d$

$F_a = (60 \div 100)\, F_h$ The thread is an important force amplifier

Stiffness of screw assembly

PART STIFFNESS $k = \frac{F}{\Delta l} = \frac{EA}{l}\left[\frac{\mathrm{N}}{\mathrm{m}}\right]$

F – force [N]

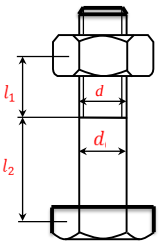
Δl – deformation [m]

E – Young's modulus [MPa]

A – section area [m²]

l – length [m]

EQUIVALENT STIFFNESS $\frac{1}{K} = \sum_i \frac{1}{k_i} = \sum_i \frac{l_i}{E_i A_i}$



BOLT STIFFNESS $\frac{1}{k_b} = \frac{4}{\pi E}\left(\frac{l_1}{d_2^2} + \frac{l_2}{d_0^2}\right)$

confined "O"-ring

$\frac{1}{k_a} = \frac{1}{k_1} + \frac{1}{k_2}$

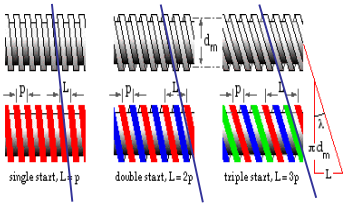
unconfined gasket

$\frac{1}{k_a} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_{gasket}}$

$\frac{1}{k_a} \cong \frac{1}{k_{gasket}}$

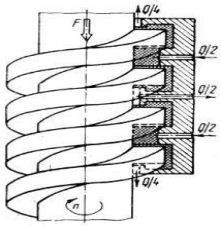
Increasing of the Efficiency

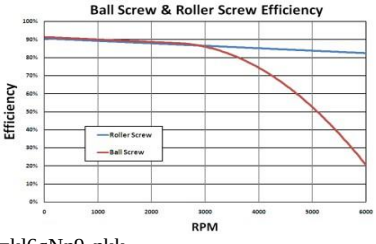
Multiple start screw



For the same pitch, l, α_2 increases

Hydrostatic screw





http://www.youtube.com/watch?v=kl6qNn9-nkk

http://www.youtube.com/watch?v=_9rtQ91PQNw

Conclusions

- Most common and used assembly is threaded assembly
- There are many kind and shapes of threaded parts:
  - bolts, screws, studs etc.
  - Nuts with washers.
- Thread is an important force amplifier based on wedge effect
- Friction is very important in threaded assemblies
- Representation of thread in technical drawings is a simplified one